



THE CHEMCAM INSTRUMENT FOR THE 2011 MARS SCIENCE LABORATORY MISSION: SYSTEM REQUIREMENTS AND PERFORMANCE

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Presentation of ChemCam

ChemCam is one of ten experiments onboard the Mars Science Laboratory (MSL) rover “Curiosity”.

ChemCam is a combination of:

- a Laser-Induced Breakdown Spectrometer (LIBS),
- a Remote Micro-Imager (RMI) camera.

The ten experiments will work together to detect and study targets of interest with remote and in situ measurements, to acquire samples of rock, soil, and atmosphere, and analyze them in onboard analytical instruments.

ChemCam is the instrument providing remote analysis capability.

This is the first use of a LIBS system in space.



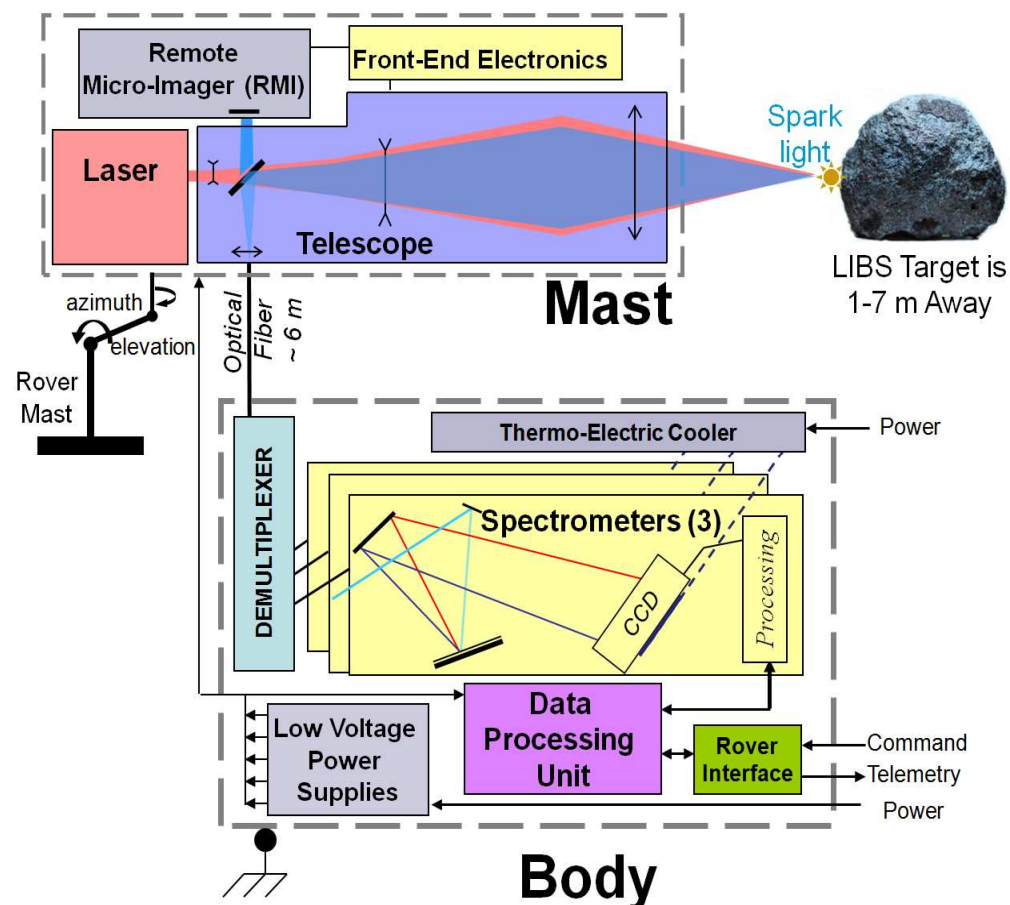
“Building Curiosity” - Photo JPL



Presentation of ChemCam (2)

The LIBS subsystem provides remote sensing data on the composition and elemental abundances of rocks and soils via active interrogation by a high-power laser, acquiring spectra of targets.

The RMI subsystem provides high-resolution images of the target regions interrogated by the LIBS laser, and is used to provide geologic context for the LIBS data.





Presentation of ChemCam (3)

ChemCam is physically divided into two units:

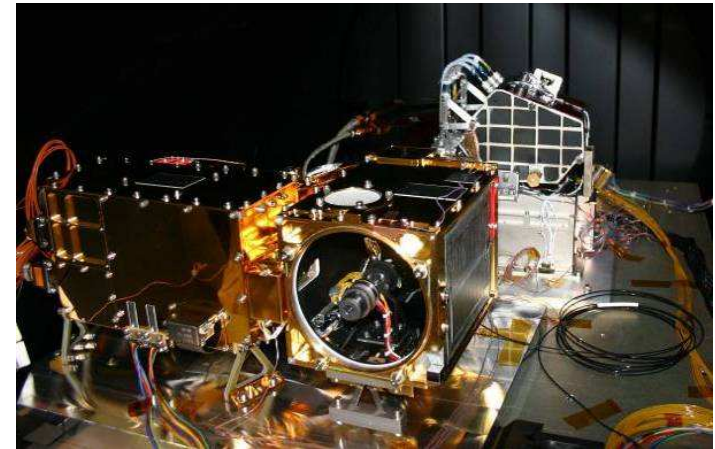
- the Mast Unit (CCMU),
- the Body Unit (CCBU).

The CCMU is located at the top of the rover mast, and consists of an optical telescope, a Nd/KGW (Neodymium doped Potassium-Gadolinium Tungstate) laser, the RMI camera and supporting electronics.

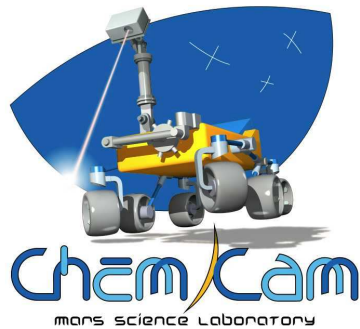
It is provided by the French part of the ChemCam team, the **IRAP** laboratory in Toulouse, which is supported by **CNES**, the French Space Agency.

The CCBU consists of an optical demultiplexer, three independent spectrometers with CCD detectors, the experiment controller, and supporting electronics, and is located inside the body of the rover. The CCBU is provided by **Los Alamos National Laboratory**.

The CCMU and CCBU are interconnected via fiber optic contributed by **Jet Propulsion Laboratory**. JPL is also supplying a thermo-electric cooler (TEC), to cool the CCBU detectors.



ChemCam in thermal test - Photo LANL



The Mast Unit (CCMU)

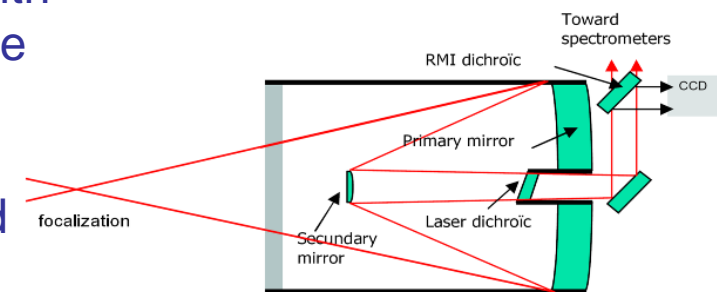
The Mast Unit consists of two boxes, the OBOX (Optical Box), and the EBOX (Electrical Box). The OBOX contains the LIBS laser source, a Galilean telescope for expanding the beam, a Cassegrain telescope, an imaging lens system, the RMI camera, and the autofocus sub-system (AF).

The LIBS laser emits bursts of pulses, which are focused by the telescope's mirror on the target. It is designed with a powerful pulsed diode-pumped solid-state laser source with a good quality laser beam.

The AF subsystem consists of a continuous-wave laser diode, the secondary mirror translation mechanism, and electrical devices allowing modulation of the signal and synchronous detection of the reflected signal.



Mast Unit – Photo CNES



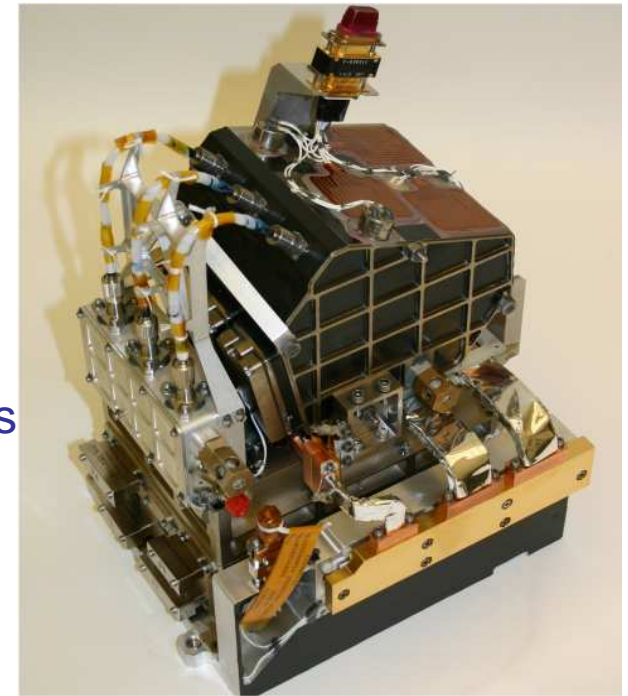
OBOX optical design



The Body Unit (CCBU)

CCBU consists of the optical demultiplexer, which splits the light into 3 broad wavelength bands, 3 spectrometers, which spectrally disperse and detect the LIBS photons, the electronics box, and the thermo-electric cooler (TEC), which cools the spectrometer CCD detectors.

The demultiplexer uses dichroic mirrors to split the wavelength ranges. The beams are re-imaged into bundles of fibers. Slits are fastened to the end of each fiber array as the entrance aperture of each spectrometer. The spectrometers are crossed Czerny-Turner optical designs, and use dielectric mirrors and holographic gratings for light dispersion. They employ e2v back-illuminated CCDs that are operated in low-noise, advanced inverted mode. The Body Unit electronics consist of a low-voltage power board, a spectrometer board, and a data processing unit (DPU) board.





ChemCam objectives and requirements

ChemCam addresses four of the five MSL mission objectives, including:

- (1) characterize the geology of the landing region,
- (2) investigate planetary processes relevant to past habitability,
- (3) assess the biological potential of a target environment, and
- (4) search for materials that would present toxic hazards to humans.

It will operate on its own, providing remote analysis, or as a strategic instrument, providing information for the team to decide other analysis.

Various analysis or investigations are requested from ChemCam:

- rapid remote rock identification,
- dust removal,
- soil and pebble composition surveys,
- quantitative analysis, incl. trace elements,
- depth profile
- calibration
- detection of water/hydration

Science Requirements for LIBS include obtaining major element abundances to $\pm 10\%$, along with minor and trace element characterization (including H, Li, Be, C, N, S).



ChemCam objectives and requirements (2)

The main system requirements are presented here:

ChemCam shall be able to acquire LIBS data, at target range of 1m to 7m, and RMI data up to infinity.

The system shall provide sufficient light from the LIBS spark to support the signal/noise ratios specified for the spectrometers.

The instrument shall be able to provide a target composition depth profile > 1 mm into a rock target at distances to at least 6 m.

The laser shall be capable of providing $> 3e6$ shots over the period of a full Mars year, and capable of providing > 3000 shots per sol.



ChemCam objectives and requirements (3)

The LIBS subsystem must provide laser energy density $> 10 \text{ MW/mm}^2$ at the sample at distances ranging from 1.5 to 7 m, in the $[-20^\circ\text{C}/+20^\circ\text{C}]$ range. Other laser requirements include pulse energy at the sample $> 13 \text{ mJ}$, pulse durations of 5-8 ns, and beam quality of $M^2 < 3$ (at laser-alone level).

The telescope must focus the laser output, at $\pm 0.5\%$ of the target distance. It must collect the photons emitted by the plasma cloud generated by the laser and transmit this light to the spectrometers, It must act as a “telephoto” lens for the RMI subsystem, which, it self, must provide a 15 mrad field of view, and a resolution of $100 \mu\text{rad}$ (with a 0.2 contrast).

The demultiplexer subsystem must divide the LIBS photons collected into three optical bands (UV = 240-340 nm, VIS = 385-465 nm and VNIR = 475-850 nm) and feed these photons to the three optimized spectrometers. The spectrometers are required to achieve optical resolutions of 0.2, 0.2, and 0.65nm (FWHM) for UV, VIS and VNIR respectively.

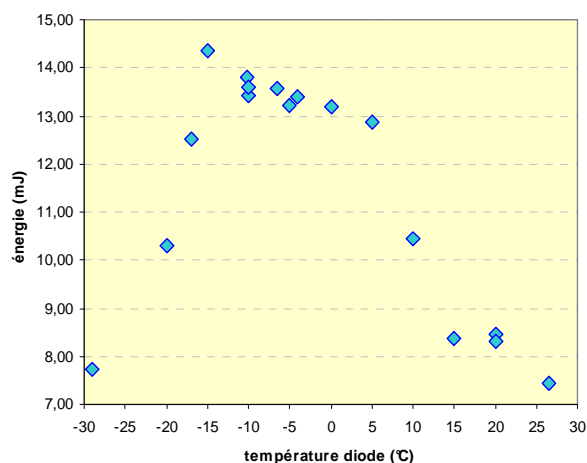


LIBS performances

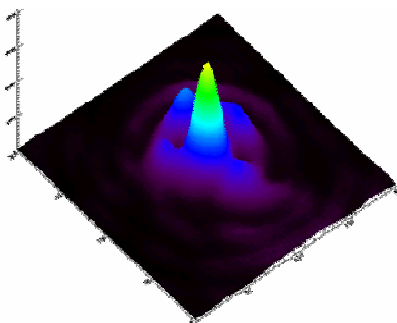
Tests have been done at CCMU, CCBU stand-alone level, then at ChemCam integrated level, and lately, at Rover level.

The “Emission” way (only Mast Unit is involved):

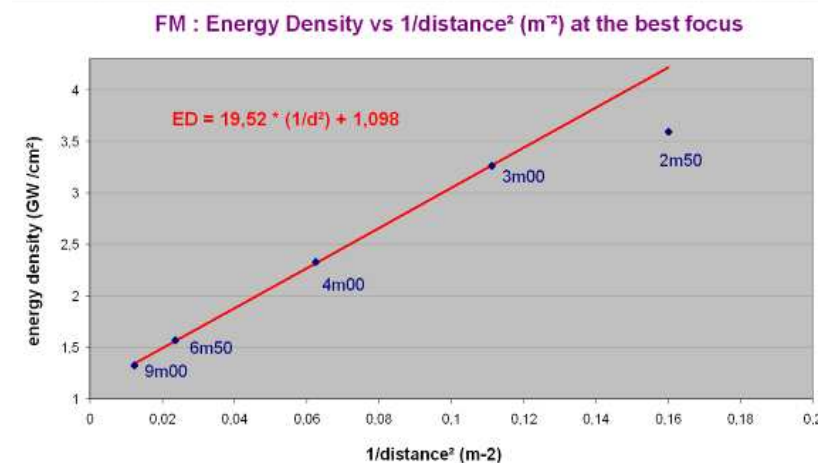
Energy:



Beam shape:



Energy density (computed):



Focusing capabilities and depth of field (DoF):

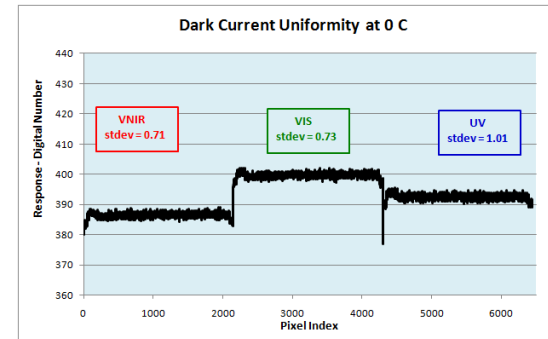
The precision of the autofocus is +/- 8 motor-steps, 1-sigma, which is better than the LIBS DoF (+/-11 steps).



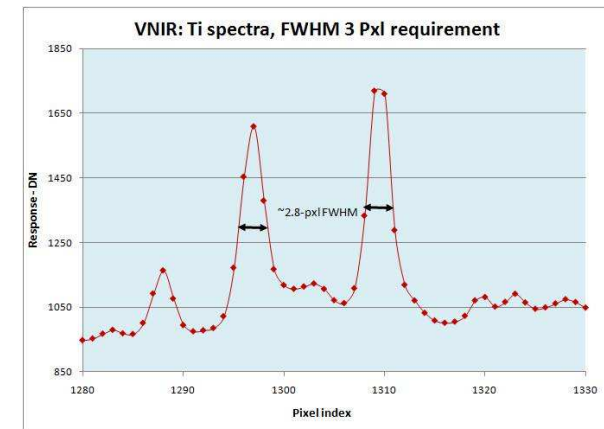
LIBS performances (2)

The “Collect” way:
CCBU performances :

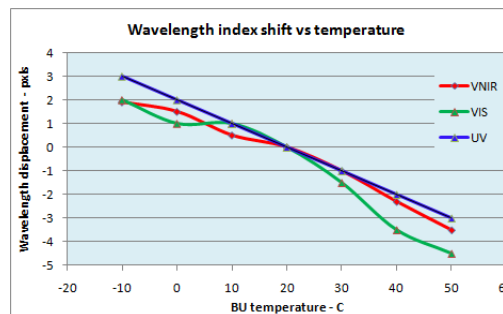
Thermal noise obtained at 0°C on CCDs
(temp. obtained with the TEC):



Spectral resolution (FWHM) on VNIR (where the requirement is the lowest):



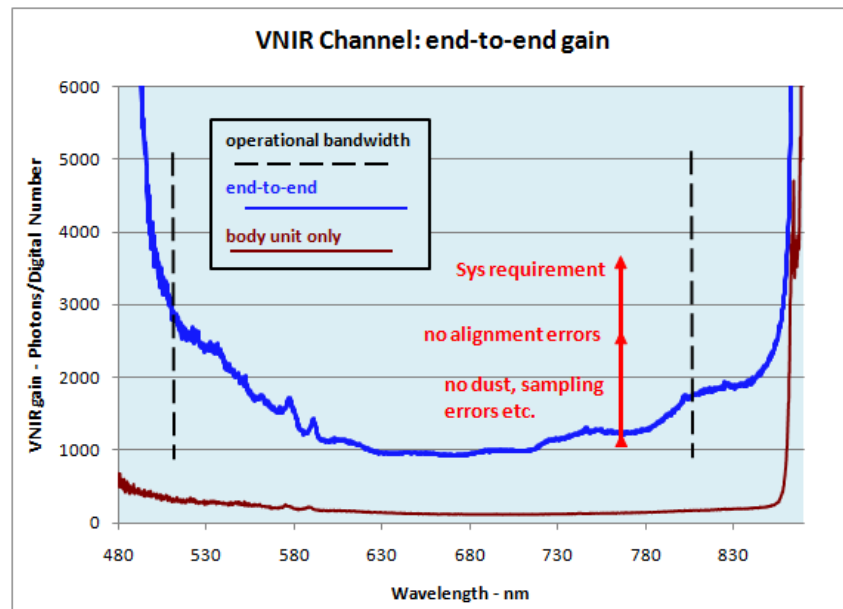
Sensibility (wavelength drift) to the temperature:



IPPW-8

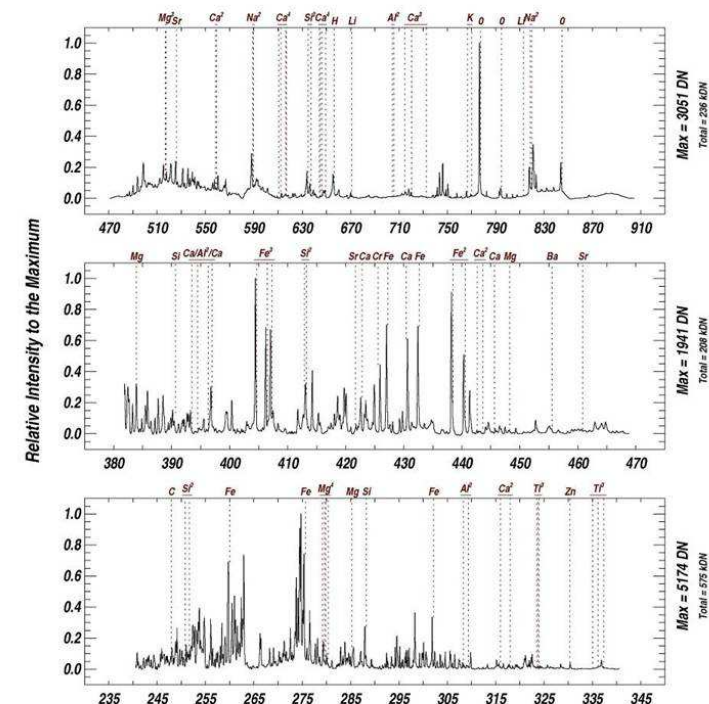


End-to-end measurements:
The “Gain” is the most important performance to reach the science objectives (shown here for VNIR)



LIBS performances (3)

End-to-end Spectra:
(here on banded-iron)



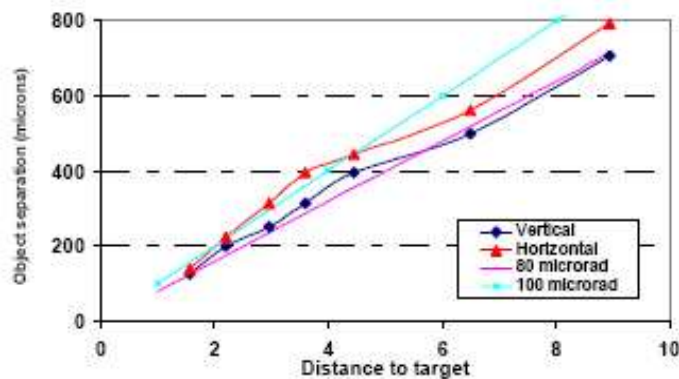
ChemCam Quicklook Wed Mar 23 22:58:08 2011 QL_CCAM_Overview1		<input type="checkbox"/> Sanity Check <input type="checkbox"/> Dark subtraction <input checked="" type="checkbox"/> Average <input checked="" type="checkbox"/> Denoise removal <input checked="" type="checkbox"/> Continuum subst. <input type="checkbox"/> Transmission <input type="checkbox"/> Wave calibration <input type="checkbox"/> Resampling	
Target: #9 Banded Fe Origin: STT tests Aquila: 2011-03-22 Distance: 2.50 1 of 5	# spect: 30 # shots: 30 Atmos: N2 8 torr Laser T: 0 C Spect T: 40-30 C		



RMI performances

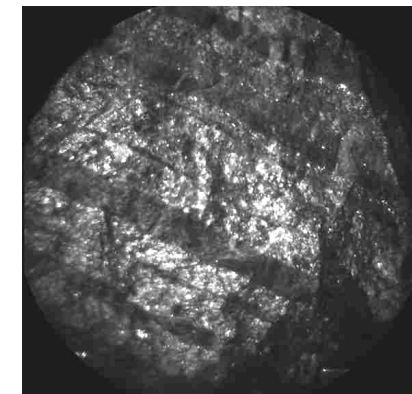
The Field-of-view has been measured at 20 mrad.

The Resolution, measured with a USAF-type target, is slightly different in the vertical and horizontal directions due to astigmatism. The object separation, at 0.2 contrast, is shown here:



Wavelength response is calculated from elemental measurements (CCD QE, lenses and dichroics measurements). The RMI camera will collect light from 0.4 to 0.9 μm . Note that only 8% to 18% of the light coming into the telescope end up in the RMI, so impact to the LIBS performance is minimal.

A Banded-Iron rock image is shown here:



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Calibration

Calibrations tests have been done to assess the capability of the Instrument to obtain major element abundances, along with minor and trace element characterization.

Two configurations have been considered:

- at optimal laser energy ($T^{\circ}\text{laser} = -10^{\circ}\text{C}$), with a limited number of standards.
- at degraded laser energy, at room temperature (69 standards).

In both cases, samples were placed in a chamber with an ambient Mars pressure (7 Torr of CO_2). Also, depth profile, soil and dust removal have been characterized.

The last opportunity has been the Rover Thermal Test in March 2011 at JPL, where MER standards have been fired with ChemCam, at 3m and 5m. Also, the on-board ChemCam calibration targets (CCCT) spectra have been acquired during this test; these CCCT will be available on Mars, for in-flight calibration.



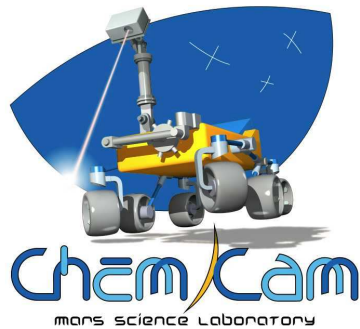
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Cal Targets - Photo LANL



References

- [1] Saccoccio M. et al. (2008), ChemCam on MSL 2009: First laser-induced breakdown spectrometer for space science. International Conference on Space Optics, 2008.
- [2] Maurice S. et al. (2009), Characterization of ChemCam (MSL) imaging capability. Lunar & Planetary Science Conference, XL, 1864.
- [4] Cousin A. et al. (2009), Chemcam (MSL) Autofocus capability, Lunar & Planetary Science Conference, XL, 1684.
- [3] LeRoch N. et al. (2010), ChemCam on the next NASA mission to Mars (MSL-2011): measured performances of the high-power LIBS laser beam, International Conference on Space Optics, 2010.
- [5] Dufour C. et al. (2010), Determination of the first level Image processing of the ChemCam RMI instrument for MSL, International Conference on Space Optics, 2010.
- [6] Wiens R.C. et al. (2011), Calibration of the MSL/CHEMCAM/LIBS remote sensing composition instrument, Lunar & Planetary Science Conference, XLII, 2370.
- [7] Cousin A. et al. (2011), Depth profile studies using ChemCam, Lunar & Planetary Science Conference, XLII, 1973.



Conclusion

ChemCam is ready to go!!!
The team is looking forward to providing remote analysis of the Martian rocks and soil...

Thanks you.

